



**HL-10 Lifting Body at the Entrance to the NASA Dryden Flight Research Center**

## **Chapter 5**

### **The HL-10 program**

Concurrent with the development of the M2-F2/F3 vehicle was the development of the HL-10 vehicle. The HL-10 lifting body evolved from work at NASA Langley.

#### **5.1 Theoretical Development**

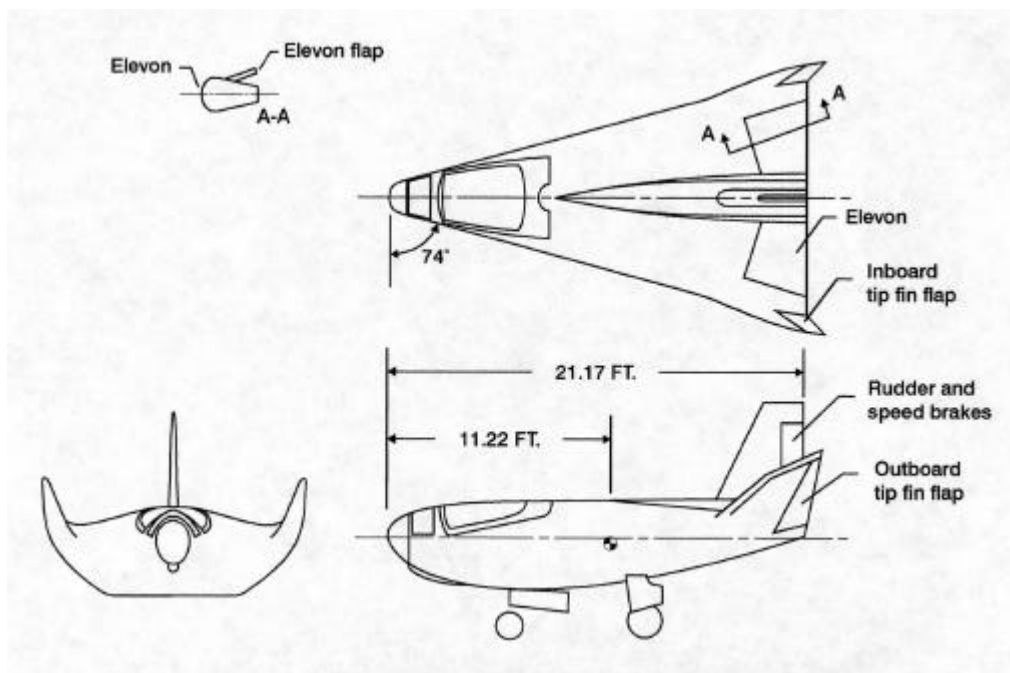
The HL-10 (Horizontal Lander, model number 10) entry configuration was developed at the NASA Langley Research Center (LaRC) under the general guidance of Gene Love, Bob Rainey and Jack Paulson. It was based on some studies initiated in 1957 that showed that an entry configuration with negative camber (cross section like an inverted wing airfoil) and a flat bottom would have good stability during entry and a slightly higher L/D than a blunt half-cone ([Reference Kempel, 1994](#)). Work continued at LaRC on the development of this concept and in 1962 the configuration was designated as the HL-10. When Bikle suggested

the construction of the heavy weight M2-F2 to NASA headquarters, the Langley engineers proposed that their HL-10 shape was a viable alternative and worthy of consideration. Headquarters approved the construction of both vehicles and the contract was awarded to Northrop in April 1964. The Langley engineers then concentrated on the development of a practical shape that could be safely flown in the transonic and subsonic flight regime, yet would retain the aerodynamic features necessary for successful atmospheric entry.

## 5.2 Technical and Physical Development

The HL-10 design team made no attempt to incorporate in their vehicle a canopy for forward visibility as was done on the M2-F2. The pilot was completely enclosed within the vehicle outer mold lines and would be totally dependent on the nose and side windows for visibility during landing.

Wind tunnel tests on the basic HL-10 continued at Langley after the contract award to Northrop. These tests showed that there were some deficiencies in directional stability around Mach 1.5 and that the subsonic L/D of the basic configuration was lower than expected. In February 1965 (10 months after contract award) Langley proposed some changes to the HL-10 configuration. The size of the center fin and tip fins was increased and additional control surfaces were added at the aft end of the vehicle to "boat-tail" the individual surfaces and reduce the base drag at low speed. Although the increased complexity of the control system was not popular with the NASA FRC team at the time, Northrop incorporated these changes during initial construction (Figure 5-1).



**Figure 5-1: Three-View Drawing of HL-10**

The HL-10 was equipped with thick elevons, left and right, at the aft edge of the body. These surfaces were deflected differentially for roll control and symmetrically for pitch control. A single, split rudder was mounted to the center vertical fin. Both sides of the rudder could be deflected together, asymmetrically for yaw control. The two sides of the rudder could be extended symmetrically to serve as a speed brake.

Secondary moveable surfaces were located on the inboard and outboard trailing edges of the tip fins and the upper surface of the elevons. These were slow moving controls designed to reduce the base area, and thus the drag, at low speed. They were also used to flare the aft end of the vehicle for added stability in the transonic region (Figure 5-2).



**Figure 5-2: HL-10 Control Surface Configurations, Subsonic**



**Figure 5-2: HL-10 Control Surface Configurations, Transonic**

Like the M2-F2, the HL-10 was equipped with a three-axis stability augmentation system which consisted of rotational rate dampers. The damper signals were mechanically added to the pilots stick and rudder commands.

The landing gear design philosophy for the HL-10 was similar to that for the M2-F2, namely, a rugged, non-optimized design with a rapid (one-second) blow-down feature. The pilots had accepted this philosophy based on the research nature of the program.

### **5.3 Construction**

The HL-10 was procured with NASA funds under the same contract and government/contractor team philosophy as the M2-F2 (discussed in Sections 4.2.1 and 4.3). Langley was still working on the final loft lines when the contract was awarded so the HL-10 construction and delivery were to follow the M2-F2. The HL-10 construction started in January 1965 and finished in January 1966 ([Figure 4-6](#)). The construction proceeded smoothly in spite of the late configuration changes mentioned earlier. Initially George Sitterle was assigned as the NASA FRC Operations Engineer for the HL-10. He was on site at Northrop during most of the vehicle construction.

### **5.3.1 Wind Tunnel and Ground Tests**

A test program was conducted in the Langley 7X10-foot High Speed wind tunnel to define the launch transients produced by the flow field of the B-52 mother ship and to define the proper carry angle for the pylon adapter. After delivery of the HL-10 to NASA FRC on 18 January 1966, the government-furnished equipment was installed. The vehicle was then trucked to the Ames 40X80-foot wind tunnel for final testing. Results were generally satisfactory although some momentary flow separation was noted on the tip fins at some flight conditions.

Since the landing gear and tires of the HL-10 were similar to the those on the M2-F2, lakebed taxi tests were not considered necessary. Flight control system checks showed some discrepancies. Filters were installed to suppress structural vibrations which were being triggered by the flight control system. An inertia "swing" was performed in a manner similar to the M2-F2 to measure the moments of inertia about all axes. By late 1966 the HL-10 was declared ready for flight.

## **5.4 Flight Testing**

Flight testing began with a glide flight in December 1966. Glide and powered research tests were concluded in July 1970.

### **5.4.1 AFFTC/NASA FRC Test Team**

The HL-10 flight test program was conducted under the auspices of the Edwards AF/NASA Lifting Body Joint Operating Committee described earlier (and in Appendix D). Most of the support functions provided by AFFTC and NASA FRC were the same as those provided to the M2-F2 program. The AF provided the B-52 maintenance and support, fire crash and rescue, and rocket engine maintenance. NASA provided the test vehicle maintenance, instrumentation, data reduction and control room operation. NASA FRC maintained flight safety responsibilities for each operation. After receipt of the HL-10 vehicle, NASA FRC assigned Herb Anderson as the Operations Engineer for the HL-10 responsible for maintaining configuration control and for overseeing maintenance and flight scheduling activities.

By the time the HL-10 was ready for flight the X-24A program had been approved and construction was under way. The AFFTC engineering team, which had been supporting the M2-F2 flight planning effort, turned to preparations for the X-24A program. The NASA engineering team therefore assumed all aspects of the HL-10 simulation and flight planning effort with minimum engineering support from the Air Force (Figure 5-3). Air Force and NASA test pilots continued to share pilot and chase responsibilities for all lifting body flights.



**Figure 5-3: NASA HL-10 Simulator**

#### **5.4.2 Glide Flight Program**

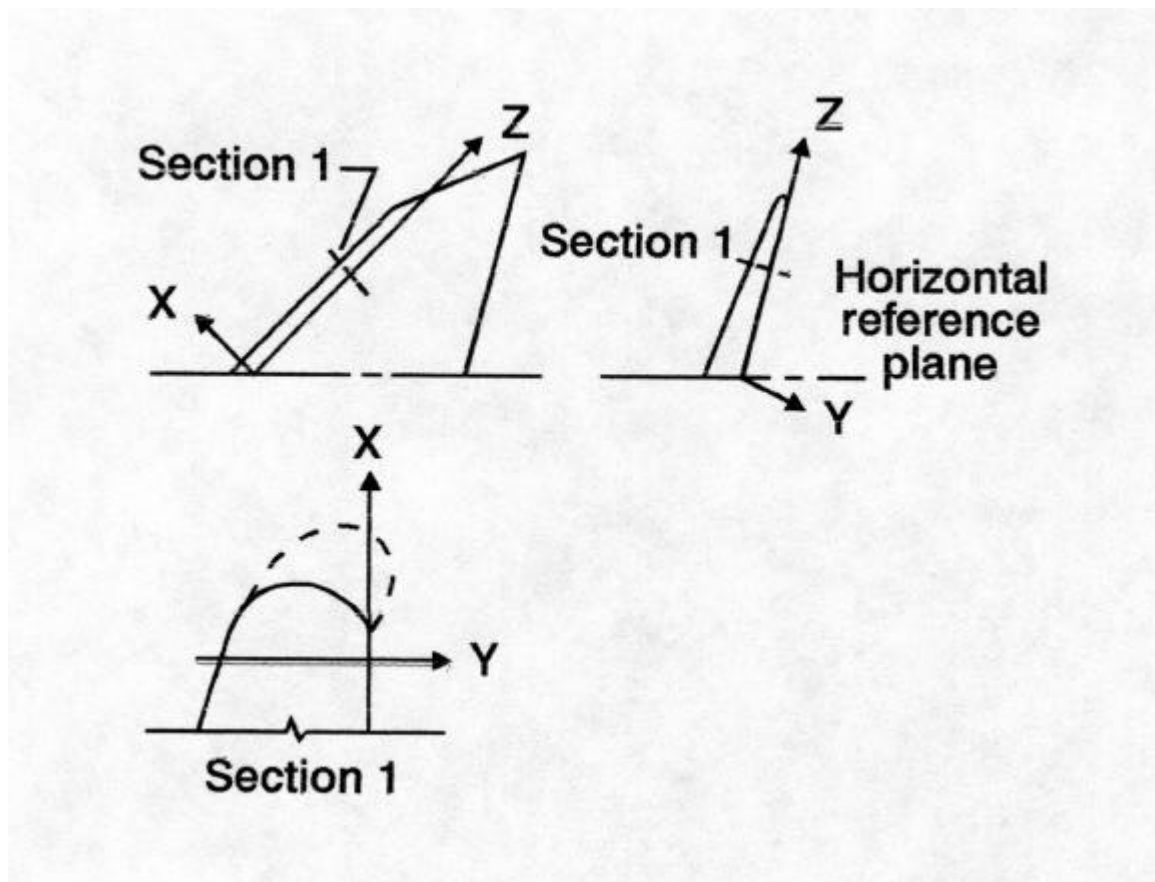
The test team initially planned to conduct two captive flights for the HL-10 to check out all subsystems. Only one was found necessary. Bruce Petersen flew the first glide flight on 22 December 1966 (Figure 5-4). Shortly after launch moderate vibrations were felt by the pilot and were observed via the telemetry in the control room. The pilot was advised to change some flight control switch positions to reduce damper gains. He did and the vibrations subsided. One of the planned maneuvers for the first flight of any of the lifting bodies was a practice flare at altitude. The purpose of this maneuver was to investigate whether the vehicle was controllable throughout the high speed approach (planned at 300 knots) and the subsequent deceleration to a low speed landing condition (expected to be about 180 knots). It also insured that the vehicle had sufficient L/D to complete the flare. As Peterson accelerated to the 300-knot high speed approach condition, he noticed that the vehicle was very sensitive in the pitch axis. He completed the practice flare and, as he was slowing down, noticed that the vehicle was no longer responding properly to pitch and roll commands. He lowered the nose and immediately regained control of the airplane. He decided to fly the final landing approach at a higher speed than originally planned so that he could land before slowing into the area of poor control. As he approached 340 knots on final approach, he again encountered some control vibrations and the vehicle became very sensitive. He completed the flare and made a successful landing, touching down quite fast, however, at about 280 knots (See Appendix B).



**Figure 5-4: HL-10 Glide Flight**

**5.4.2.1 Analysis, Test and Redesign:** The flight control vibrations of that first glide flight were a result of an error in the predicted elevator effectiveness and an improper filter in the rudder flight control electronics. These discrepancies, along with the overly sensitive pitch control, were quickly identified and easily rectified. The loss of control at low speed was a more difficult problem to identify. It took several weeks before the data were fully analyzed and correlated. The problem was identified as a separation of the airflow over the upper surface of the outboard fins. This flow separation caused the elevons to become ineffective ([Reference Kempel, 1994](#)).

The NASA Langley aerodynamicists returned to the wind tunnel. Soon they were able to duplicate the flow condition experienced in flight, a condition observed in earlier tests (and in the full scale tests at Ames) but dismissed as spurious scatter in the data. Langley devised several "fixes" and presented them to the NASA FRC Lifting Body team (now headed by Program Manager Gary Layton). NASA FRC selected adding an inward-cambered glove to the leading edge of the tip fins (as shown in Figure 5-5). This glove allowed the airflow to stay attached to the upper surface of the tip fins at high angles of attack (low speeds).



**Figure 5-5: Inward-Cambered Glove Modification to HL-10 Fins**

The entire process of retesting in the wind tunnels, redesigning the fins, manufacturing the gloves, installing them, and retesting the control system took over one year. Since the problem flight condition had been successfully duplicated in the small scale wind tunnels, NASA FRC decided that a return to the full-scale tunnel was unnecessary. The second glide flight occurred on 15 March 1968. It achieved a more reasonable approach speed of 300 knots and a normal touchdown speed below 200 knots. The flight was quite successful and was followed by nine more glide flights to refine the control system and prepare for powered flight.

#### **5.4.3 Powered Flight Program**

NASA FRC pilot John Manke performed the first rocket powered flight of a lifting body on 13 November 1968. The vehicle was the HL-10. An earlier attempt in the same vehicle by AF Major Gentry had failed when the rocket engine malfunctioned after launch. The flight envelope of the HL-10 was expanded gradually on successive flights by igniting two, then three, then all four of the chambers of the XLR-11 rocket engine. The first supersonic flight was accomplished on 9 May 1969, and by February 1970 the HL-10 had attained a maximum Mach number of 1.86 and a maximum altitude of 90,300 feet - - the fastest and highest of any of the lifting bodies (Reference Kempel, 1994).

The final two flights of the HL-10 explored the potential use of low thrust during the landing to produce an approach angle that was less steep, and more "airplane-like." For these tests the XLR-11 engine had been removed and had been replaced by three hydrogen peroxide emergency landing rocket engines (approximately 300 pounds of thrust each). A relatively large propellant tank was also installed. This allowed the pilot to light the rockets on final approach and thereby reduce the approach angle from about 18 degrees to only 6 degrees.

Both landings were made on the south lakebed runway number 17 which was seven miles long. The plan called for the pilot to maintain an airspeed of 280 knots while the HL-10 was on the 6-degree flight path with the rockets burning. At 200 feet altitude the pilot would shut off the rockets and lower the landing gear. He would then perform a deceleration and gentle flare to landing (Figure 5-6). Captain Pete Hoag flew both of these flights and his comments were quite negative. He reported that the shallow approach made it difficult for him to judge where the airplane would touchdown. The nose-high attitude during the entire maneuver forced the pilot to rely on the nose window, and its resulting poor depth perception, for a long time before touchdown.



**Figure 5-6: HL-10 Landing**



**Pilot Bill Dana, the HL-10 and the B-52 Fly-over**

The largest deterrent to a low-thrust, rocket-powered landing, however, was the need to establish a safe procedure to land the airplane if the rockets did not fire. For the two tests, the pilot set up for an unpowered landing on the near end of the seven-mile runway. At some pre-determined altitude he would try the rockets. If the rockets failed to light, he would land close to the near end of the runway. If the rockets worked properly, he would establish a new aim touchdown point about four miles farther down the runway. This procedure was not very practical for a runway of normal length. The tests successfully pointed out the need for alternate-runway planning for any future entry system that required an engine to be started after entry, but before landing.

**5.4.3.1 Handling Qualities:** The handling qualities of the HL-10 on the second glide and all subsequent flights were quite good. The vehicle was susceptible to rather abrupt rolling motion in turbulence, as were the M2 and X-24A vehicles. It had exceptionally good inherent damping characteristics with the stability augmentation system disengaged. Even after several control system improvements, however, the HL-10 was still slightly sensitive in the pitch axis during the high speed final approach. A transonic pitch trim change occurred between 0.97 and 0.96 Mach number. The magnitude of the trim change was as expected, but the trim change was much more abrupt than predicted, apparently a result of an abrupt flow change or shock wave movement. (Additional pilot comments are included in Appendix B.)

**5.4.3.2 Schedule and Pilots:** A total of five pilots participated in the HL-10 program which included 13 glide flights and 24 powered flights.

<u>Pilot</u>	<u>Glide Flights</u>	<u>Powered Flights</u>
Bruce Peterson	1	0
Captain Jerry Gentry	7	2
John Manke	3	7
Bill Dana	1	8
Major Pete Hoag	1	7

(The schedule relative to the other lifting bodies is shown in [Figure 2-1](#). A complete log of flights and pilots is included in Appendix C.)

## 5.5 Technology Lessons Learned

Some new and different lessons were learned through the successful flight testing of the HL-10. These lessons, when combined with lessons learned with the sister ship, the M2-F2/F3, provide an excellent starting point for designers of future entry vehicles.

### 5.5.1 Accidents/Incidents

There were no major incidents or accidents associated with the HL-10 test program beyond the rather frightening first glide flight. This safety record is a tribute to the dedicated engineers and pilots of the Lifting Body team.

### **5.5.2 Validations**

After correction of the local tip-fin flow separation problem of the first glide flight, the flight test data validated wind tunnel predictions for stability and L/D from transonic down to landing speeds. The flat-bottom, negative-camber concept did produce a flyable and landable vehicle which had an L/D that was 14 percent higher than the M2 half-cone concept (Reference Kempel, 1994). The additional complexity of the "boat-tail" control surfaces (added during the initial construction) proved to be a worthwhile investment and probably produced much of this difference in L/D.

The HL-10 was judged to be the best handling of the three original heavy-weight lifting bodies (M2-F2/F3, HL-10, X-24A). The HL-10 also achieved the highest speed and altitude of any of the lifting bodies.

### **5.5.3 Improvements**

NASA FRC selected the HL-10 to explore potential advantages of powered approaches during landing because the vehicle had the best low speed handling qualities, and the smallest landing gear trim change, of the three early lifting bodies. The results of the tests were largely negative, however, and only two powered approaches were flown.

### **5.5.4 Problems Resolved**

Although the first HL-10 glide flight was completed successfully, four serious problems were encountered. It is remarkable that, based on a single flight that lasted a mere three minutes and seven seconds, all of these problems were identified and subsequently corrected. The problems were directly or indirectly a result of misinterpretation of wind tunnel data. The tip fin stall was corrected through additional wind tunnel tests which duplicated the condition and allowed aerodynamicists to develop suitable modification options. A glove was added to the fin leading edge to improve flow over the tip fins at moderate and high angle of attack. Two different flight control vibrations were the result of errors in the predictions of both rudder and elevon effectiveness. These were suppressed by altering the flight control electronics. The high stick sensitivity was related to the error in control effectiveness and was corrected easily by altering the stick gearing. Participating engineers learned some valuable lessons on how to interpret wind tunnel data.

On one of the early captive flights a test of the propellant jettison system was planned. At the initiation of jettison a violent vibration began. Both the HL-10 pilot and the B-52 crew felt the vibration. It stopped when the HL-10 pilot turned the flight control stability augmentation off. Apparently the pulsing of the jettison had triggered a structural vibration in the B-52 wing/pylon/adaptor that was sustained by the HL-10 flight control system. Subsequent captive jettisons were done with the stability augmentation off.

### **5.5.5 Unresolved Problems**

The HL-10 program left a few problems unresolved. For example, the visibility through the nose window was distorted such that the depth perception near landing was poor (as indicated in Appendix B). Pilots adapted to this visibility restriction and landings were easily accomplished. A substantial ablation heat shield would be required over the entire nose area on a mission vehicle, however, and some other provision for pilot landing visibility would be required. This problem, which was similar for the HL-10, M2-F2/F3, was never seriously addressed during the Lifting Body program at Edwards.

The degradation in performance and stability that would be caused by the roughened surface of an ablative heat shield after entry was not factored into the Lifting Body flight test program. Subsequent analysis (discussed in Chapter 8) showed that this degradation was sufficient to raise serious questions as to the true land-ability of these vehicles following an actual entry.

### **5.6 Test Sites**

The test sites for the HL-10 flight test program were the same as for the M2-F2/F3 program - all at AF and NASA properties at Edwards AFB. The two vehicles were stable mates in every sense of the word and used many common subsystems.

### **5.7 Current Status of Aircraft**

Following an unfortunate handling accident - the vehicle was damaged while being repositioned for display in San Diego, California - the HL-10 was restored to display status. It was mounted on a pedestal in front of the NASA FRC building and was dedicated in a ceremony on 3 April 1990.